Ocean Acoustics and Signal Processing for Robust Detection and Estimation

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LONG TERM GOALS

The long term goal of this project is to develop efficient inversion algorithms for successful estimation and detection by incorporating (fully or partially) the physics of the propagation medium. Algorithms will be designed for robust ASW localization and detection and also for marine mammal localization and tracking.

OBJECTIVES

1. Achieve accurate and computationally efficient source localization by designing estimation schemes that combine acoustic field modeling and optimization approaches.

2. Develop methods for passive localization and inversion of environmental parameters that select features of propagation that are essential to model for accurate inversion.

APPROACH

During the past year, the focus of our research was on linearized inversion, maximum a posteriori estimation of time delays and amplitudes using Gibbs sampling, and signal detection using a generalized likelihood ratio test employing maximum a posteriori estimates of delays and amplitudes of multipath arrivals.

The inversion work, extending work in [1,2,3,4,5,6] was performed in collaboration with Dr. Xiaoqun Ma, recipient of a 2000 ONR graduate traineeship award. A hybrid linearization inversion method using both least squares and regularization was implemented, and estimation was performed for source and receiver location, bottom depth, and sound speed [6,7]. Sound speed inversion was based on empirical orthogonal function modeling.

Inversion using linearization applied to arrival time information as described above requires accurate identification of multipaths at receiving phones. The Gibbs sampling Maximum a Posteriori estimation scheme the PI has developed [5,6] was further extended in order to achieve such identification; the method estimates time delays and amplitudes through the numerical computation of the joint posterior probability density function of all unknown parameters, which is difficult to track

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14. ABSTRACT
The long term goal of this project is to develop efficient inversion algorithms for successful estimation and detection by incorporating (fully or partially) the physics of the propagation medium. Algorithms will be designed for robust ASW localization and detection and also for marine mammal localization and tracking.

15. SUBJECT TERMS

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analytically. This distribution is constructed through iterative sampling from conditional distributions of the involved parameters.

RESULTS

Inversion using linearization was tested on synthetic data with excellent results. Figure 1 shows histograms for source range, source depth, and the coefficient of the first eigenvector in sound speed empirical orthogonal function modeling obtained from 500 Monte Carlo runs for synthetic data; uncertainty of 0.5, 1, and 2 ms was considered in the arrival times. Although Figure 1 only shows estimates of three parameters, inversion was simultaneously performed for source depth, five receiver depths, source-receiver range for five receiving elements, bottom depth, and the sound speed coefficient.

The linearization inversion method was subsequently applied to the Haro Strait data, provided by Dr. Ross Chapman, for the estimation of source location, array element localization, bottom depth, and sound speed. The results were very close to reference values. Figure 2 shows array element localization results for five phones obtained for one of the test cases; the estimated array shape was obtained as expected. The method was compared to broadband incoherent matched field processing. Because of a complex, largely unknown environment, matched field processing was unsuccessful in source localization, while also its computational load was significantly larger than that of linearization.

The Maximum a Posteriori time delay estimation method was compared to a simple matched filter and a simulated annealing approach [8]. Both simulated annealing and Gibbs sampling approaches performed better than the suboptimal (in the case of closely spaced arrivals) matched-filter. In terms of efficiency, the Gibbs sampling approach demanded significantly less computational time for convergence than simulated annealing. The estimation research project was carried out in collaboration with Michele Picarelli.

The Gibbs sampling approach was also applied to a detection problem, combined with a generalized likelihood ratio test (the detection work was performed in collaboration with Urmi Ghosh-Dastidar, recipient of a 2001 ONR Graduate Traineeship Award). ROC curves were constructed comparing the Gibbs Sampling-generalized likelihood ratio processor to the Replica Correlation Integration processor [9,10], developed for multipath environments. Comparison of the curves indicates the superiority of the proposed processor.

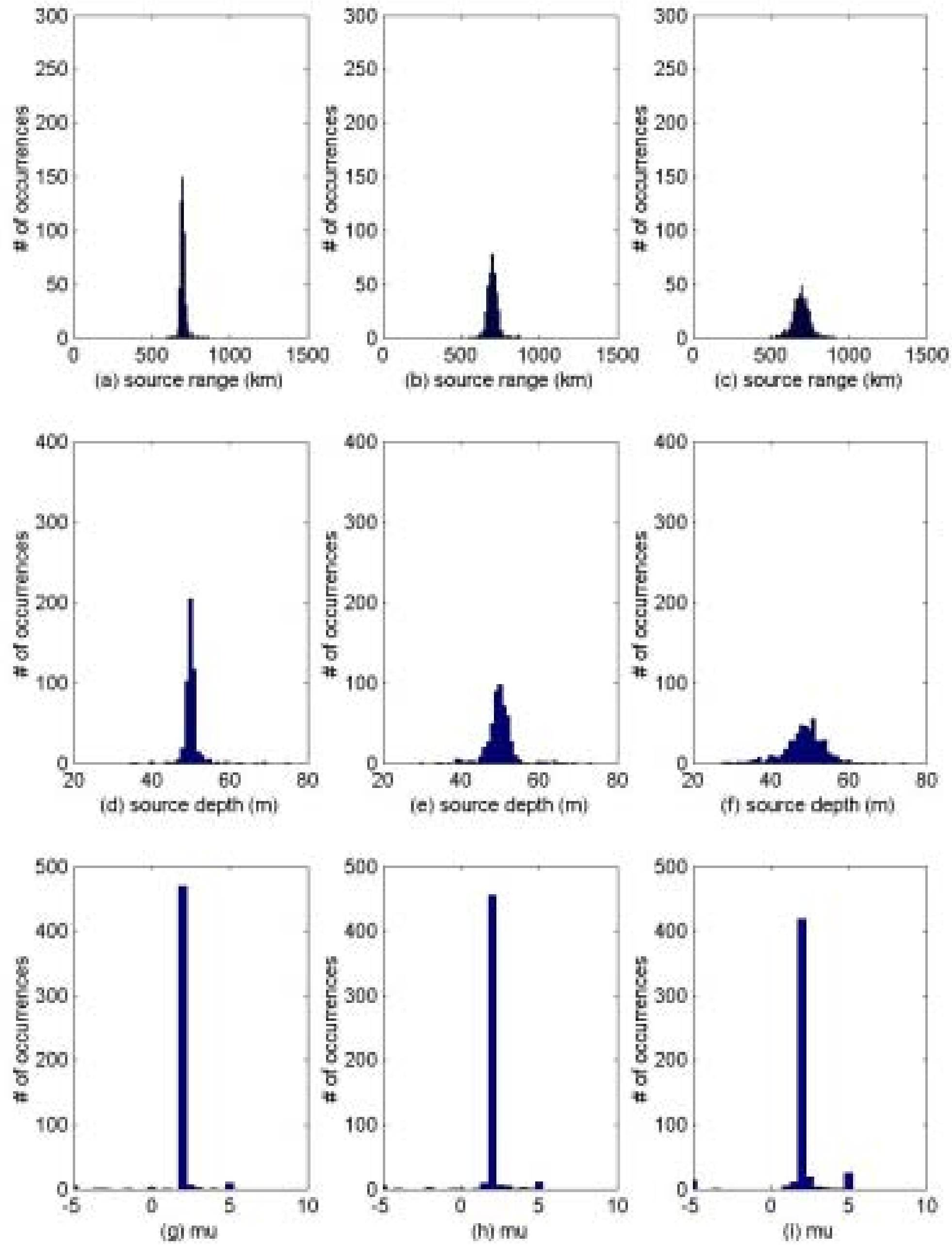

Figure 1: Linearized inversion histograms from 500 realizations for source range, depth, and sound speed coefficient. Figures (a), (d), and (g) correspond to a temporal uncertainty of 0.5 ms, figures (b), (e), and (h) correspond to a temporal uncertainty of 1 ms, and figures (c), (f), and (i) correspond to a temporal uncertainty of 2 ms. The true parameter values are 700 m, 50 m, and 2 for source range, source depth, and sound speed coefficient, respectively.

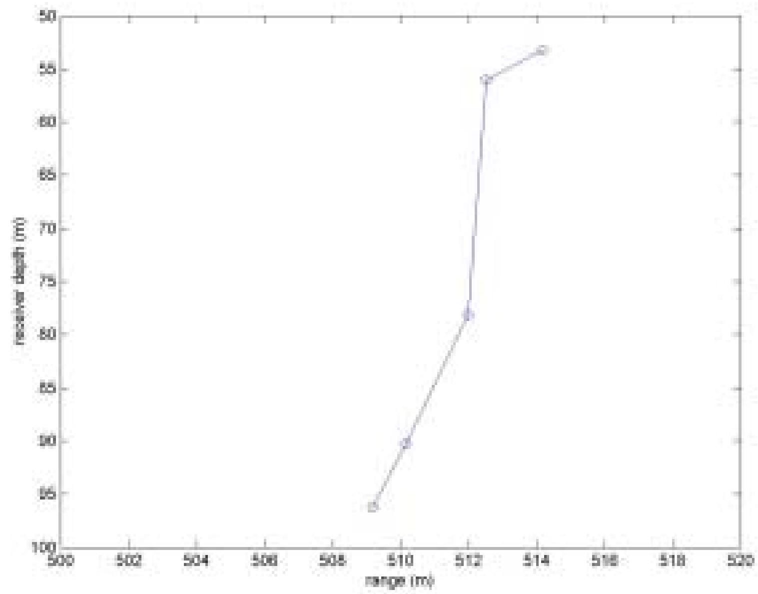

Figure 2: Receiver location estimates in the Haro Strait.

IMPACT

The methods developed in this project facilitate passive localization and detection in the ocean. Inversion using select arrivals and linearization is an efficient method for source localization, requiring significantly fewer calculations than full field matching approaches. The method can be used as a preprocessing step, before an inversion approach such as matched field processing is implemented. Linearized inversion provides accurate information on some parameters, that can then be used to reduce the search space in which matched field processing will look for the global solution. Also the Gibbs sampling-maximum a posteriori arrival identification approach approximates the optimal maximum likelihood approach [11] without the same computational demands; the method gives accurate estimates of time delays and amplitudes, whereas it also provides an estimate of the posterior probability distribution of those parameters (most time delays and amplitude estimation techniques only give point estimates). The estimated probability distribution function captures and reveals the uncertainty in the estimation process. Figure 3 shows a sample of such a posterior probability distribution function of time delays and amplitudes; for this example three multipaths are present (the number of distinct arrivals is assumed to be known). The estimates for time delays are samples 30, 80, and 121; the amplitudes are estimated to be 120, -100, and –120. The correct parameter values are 30, 80, and 85 for time delays and 100, -90, and 85 for amplitudes. Although the estimation process "misses" the third arrival, which is not included in the three major modes of the estimated posterior probability distribution of Figure 3, this arrival (at 85 for time delay and 85 for amplitude) can be identified by observing carefully the probability distribution.

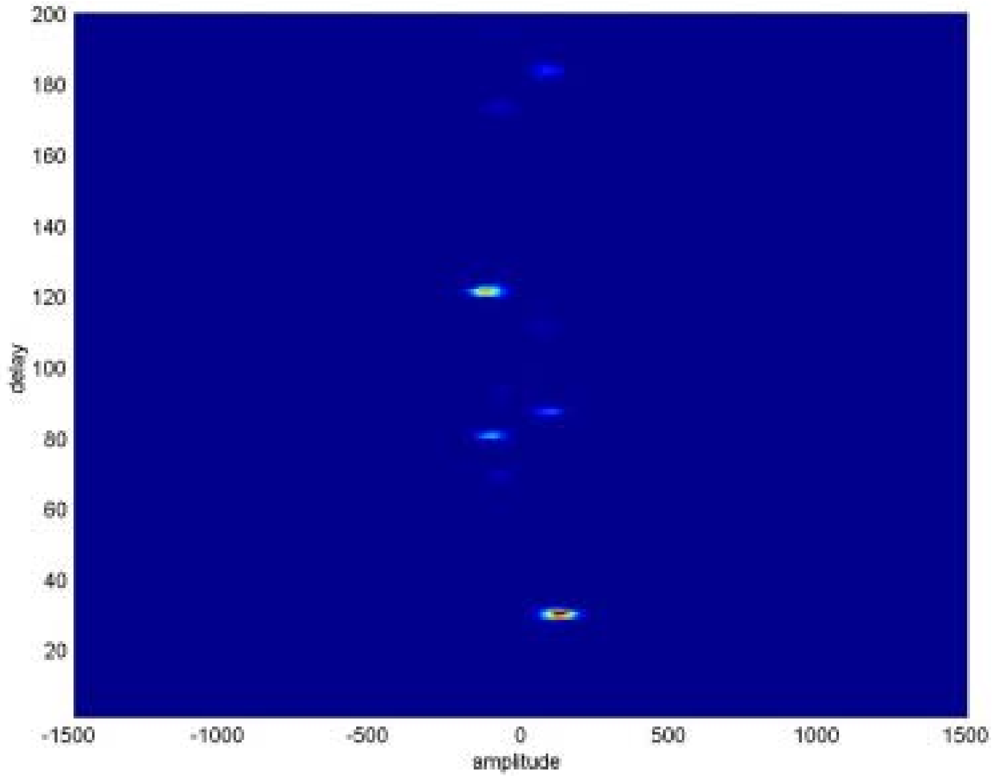

Figure 3: Estimated probability density function using Gibbs sampling.

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